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5 SENSITIVITY ANALYSIS

Note to Readers:

This chapter describes the results of the work conducted by District staff to evaluate the sensitivity of stage to changes in model parameters for the SFWMM v5.5. The 2005 Peer Review Panel made significant recommendations regarding improvement of both sensitivity and uncertainty analyses. The District intends to continue its efforts to improve the analyses. This documentation will be updated accordingly. However, at this time, the documentation presented hereafter does not fully incorporate all the recommendations from the Peer Review Panel.

Sensitivity analysis is the process of varying model input parameters and evaluating how model output changes with such variations. The significance of model sensitivity analysis is two-fold:

1. It provides information on the behavior of model output to input parameters which, in turn, can be used in model calibration.
2. It gives insight in establishing priorities related to future data collection efforts.

The sensitivity analysis is distinguished from that of the uncertainty analysis. The sensitivity analysis is a measure of the relative importance that each input parameter has on the range of simulated outputs. Whereas, an uncertainty analysis quantifies the confidence one can have with particular output variables. While the sensitivity analysis often is limited to parameter sensitivity, the uncertainty may be generated by a number of factors including: 1) parameter uncertainty, 2) model spatial and temporal resolution, 3) availability and quality of data, and 4) model algorithm. This chapter deals with sensitivity analysis as applied to version v5.5 of the South Florida Water Management Model (SFWMM).

5.1 METHODOLOGY

The sensitivity of the output variables to variations in input parameters is estimated by the traditional approach of varying one parameter at a time. A sensitivity matrix is set up that summarizes the response at model cells where corresponding gages are located, to changes in individual parameters. Model response is expressed in terms of simulated nodal stages within the model domain. The following input parameters are systematically varied universally over the whole model domain in order to analyze model output sensitivity:

1. Effective Roughness Coefficient for overland flow (ERC)

In the model, the Effective Roughness Coefficient is simulated as an exponential function of ponding depth: $N = A(POND)^b$.

2. Reference ET for Wetland (WPET)

The calculation of ET in the model is based on reference crop ET which is adjusted according to crop type, available soil moisture content, and location of the water table. In non-irrigated areas such as the Water Conservation Areas (WCAs), Everglades National Park (ENP) and part of the Big Cypress National Park (BCNP), three assumptions are made: (1) moisture content between land surface and water table does not change; (2) ET comes only from the saturated zone and/or ponding; and (3) infiltration equals percolation. Total ET is calculated as the sum of open water evaporation and saturated

zone (water table) ET. This part of ET variation is represented by the parameter WPET in the Sensitivity Analysis.

3. Potential ET for Coastal areas (CPET)

In irrigated areas within the Lower East Coast (LEC), a simple accounting procedure is used to calculate unsaturated zone ET while saturated and open water ET are calculated based on the reference crop ET. The SFWMM model simulation of this part of ET gets input from running the Agricultural Field Scale Irrigation (AFSIRS) model. This part of ET is represented by the parameter CPET in the Sensitivity Analysis.

4. Groundwater Hydraulic Conductivity (GWHC)

This parameter describes the groundwater flow rate through different types of land.

5. Seepage Coefficient (SEEP)

The SFWMM model grid size is too coarse for modeling local groundwater phenomenon such as levee seepage. In the model, an empirical levee seepage equation is used to solve for levee seepage.

6. Detention Parameter (DET)

This parameter represents the ponding depth below which no overland flow is allowed to occur for different land use types.

7. Canal-groundwater Hydraulic Conductivity (CHHC)

This parameter describes the hydraulic connectivity between the canal and aquifer.

8. Storage Coefficient (STOC)

The Storage Coefficient is the volume of water that an aquifer releases from storage per unit surface area of the aquifer per unit change in head.

Since the ranges of acceptable parameter values to be used for sensitivity analysis are not available in the literature, parameters were varied over a range for which the model calibration was assumed to remain valid (Loucks and Stedinger, 1994). Acceptable ranges of variation for input parameters were decided based on the model output response to the change of parameters.

A sensitivity or influence matrix is set up that summarizes the response at model cells where corresponding gages are located, to changes in individual parameters. Each element of this matrix can be represented by the following relationship (Trimble, 1995a):

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{y_j^c - y_j^o}{\Delta x_i} \quad \forall i = 1, \dots, n; j = 1, \dots, m \quad (5.1.1)$$

where:

α_{ij} = sensitivity of the j^{th} simulated output/performance to the i^{th} parameter;

y_j = j^{th} model simulated output/performance;

x_i = i^{th} parameter being tested;

n = number of parameters being studied;

m = number of model cells where gages are located;

o = simulated output/performance corresponding to the original calibrated parameter;

c = simulated output/performance corresponding to the parameter which is changed by an incremental Δx_i .

A matrix factorization technique – single value decomposition (SVD) is applied to the sensitivity matrix in order to understand the relationships between the parameters, and isolate groups of parameters that are dependent on one another (Lal, 1995).

5.2 RESULTS OF SENSITIVITY ANALYSIS

Sensitivity of model output by varying key input parameters is quantified by calculating the bias and root mean square error (rmse) of the simulated water levels versus observed water levels at selected model nodal locations. For each parameter, series of model runs were completed to determine a range of acceptable values such that each parameter value within the range can be used without significantly affecting the calibration. The results are grouped by magnitude of errors (expressed in terms of bias and rmse) in each region. By using this method of analysis, one is able to determine whether the variation of a parameter affects all monitoring gages or just a subset of monitoring gages.

Figures 5.2.1 and 5.2.2 show the response of the output stages in terms of bias and rmse at all gages in the WCAs at the key percentile points (5th percentile; lower quartile; median; upper quartiles and 95th percentile) for each parameter change. It can be seen that increasing or decreasing the parameter WPET slightly would not increase the bias immensely. If the change of WPET is within $\pm 20\%$, the calibration of the model won't be affected significantly. To keep the modeling output valid, the recommended change of WPET is $\pm 20\%$. This is assumed to be the upper and lower limit of the recommended parameter value for WPET.

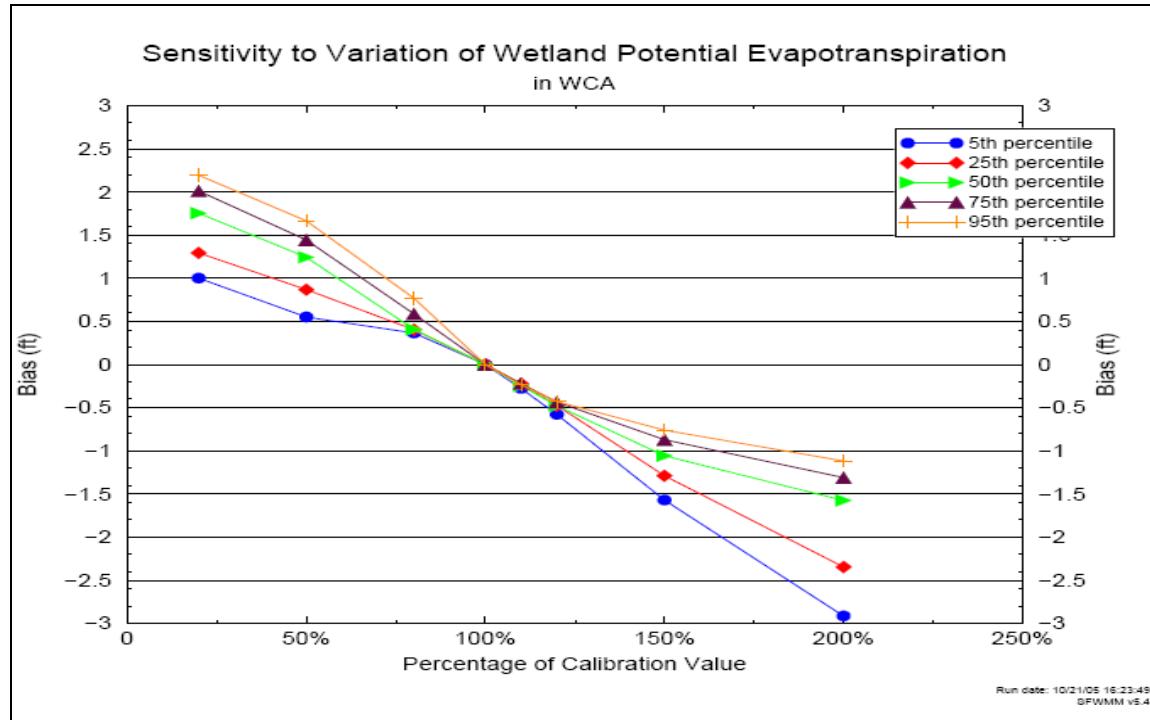


Figure 5.2.1 Sensitivity Percentile in terms of Bias to Variation of Wetland Potential Evapotranspiration in WCAs

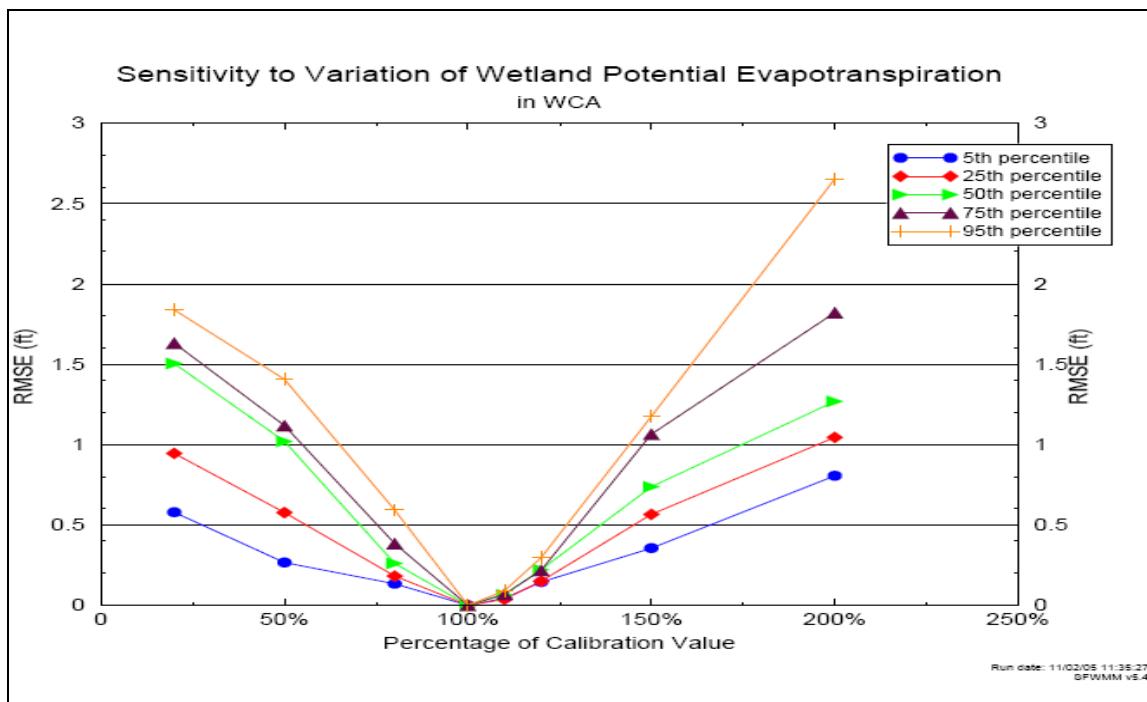


Figure 5.2.2 Sensitivity Percentile in terms of Root Mean Square Error to Variation of Wetland Potential Evapotranspiration in WCAs

Based on the response of the model output, a $\pm 50\%$ variation of the calibration value is recommended (Trimble, 1995a) for all parameters except the coastal and wetland ET. For Coastal PET, a $\pm 30\%$ change from the calibrated value is recommended to represent the upper and lower limit of parameter value; while for Wetland PET, as shown in the plots, a $\pm 20\%$ change from the calibrated value is recommended. The recommended parameter variation is summarized in Table 5.2.1.

Table 5.2.1 Recommended Parameter Variation limit

Parameter	Recommended parameter variation limit
WPET	$\pm 20\%$
GWHC	$\pm 50\%$
CHHC	$\pm 50\%$
DET	$\pm 50\%$
SEEP	$\pm 50\%$
ERC	$\pm 50\%$
CPET	$\pm 30\%$
STOC	$\pm 50\%$

Figures 5.2.3 to 5.2.9 show the components of the sensitivity matrix for stages at different monitoring gages for different regions within the model domain including: BCNP, ENP, Lower East Coast Service Areas (LECSAs) 1-3, WCAs and Canals.

Equation 5.1.1 was modified as follows:

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{O_{upper} - O_{calibrated}}{P_{upper} - P_{calibrated}} \quad \forall i = 1, \dots n; j = 1, \dots m \quad (5.2.1)$$

where:

O_{upper} = output variable value (stage) when input parameter is set at upper limit;

$O_{calibrated}$ = output variable value when input parameter is set at the calibrated value;

P_{upper} = parameter value at the recommended upper limit;

$P_{calibrated}$ = parameter at the calibrated value.

The response of the output variables was normalized to be the response per 100% change of each parameter value. For example: for WPET, the parameter value at the recommended upper limit is assumed to be a 20% increase from the calibrated value. Equation (5.2.1) is modified as follows:

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{O_{upper} - O_{calibrated}}{P_{upper} - P_{calibrated}} = \frac{Stg_{120\%} - Stg_{100\%}}{P_{WPET120\%} - P_{WPET100\%}} = \frac{Stg_{120\%} - Stg_{200\%}}{0.2} \bullet \frac{1}{P_{WPET100\%}} \quad (5.2.2)$$

where $\frac{Stg_{120\%} - Stg_{100\%}}{0.2}$ is the component of the sensitivity matrix used in the Sensitivity Analysis.

The sensitivity matrices for all regions are shown in Figures 5.2.3 to 5.2.9.

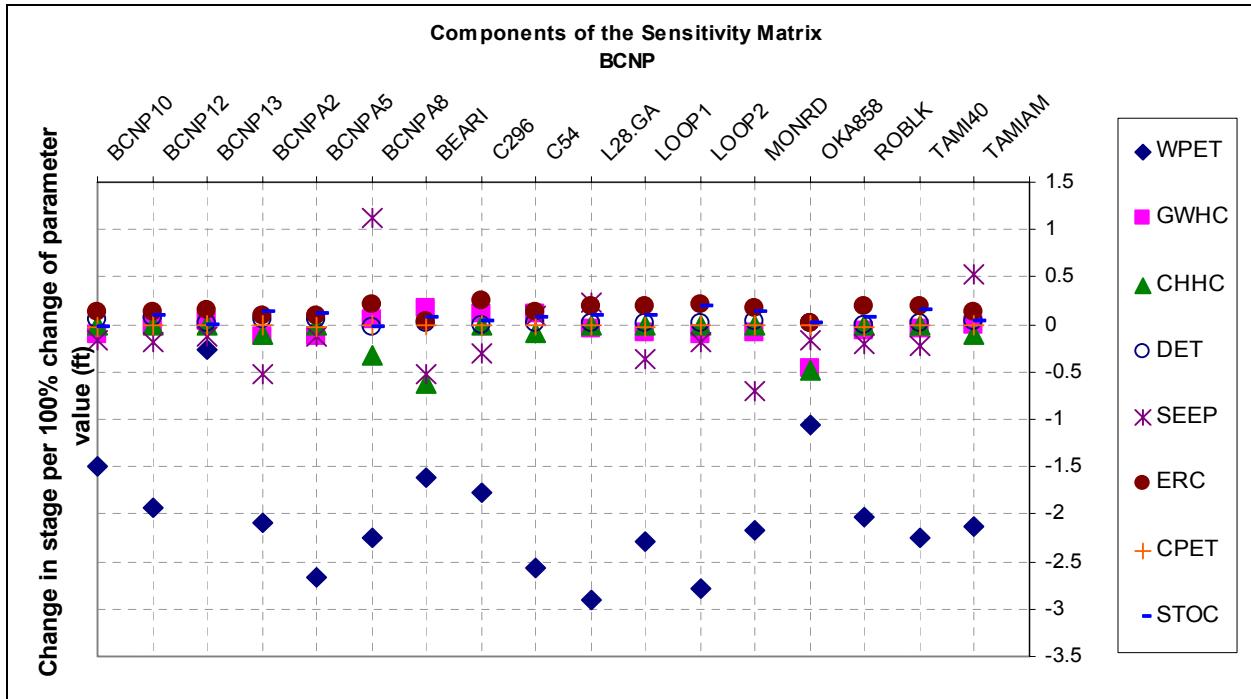


Figure 5.2.3 Components of the Sensitivity Matrix for BCNP

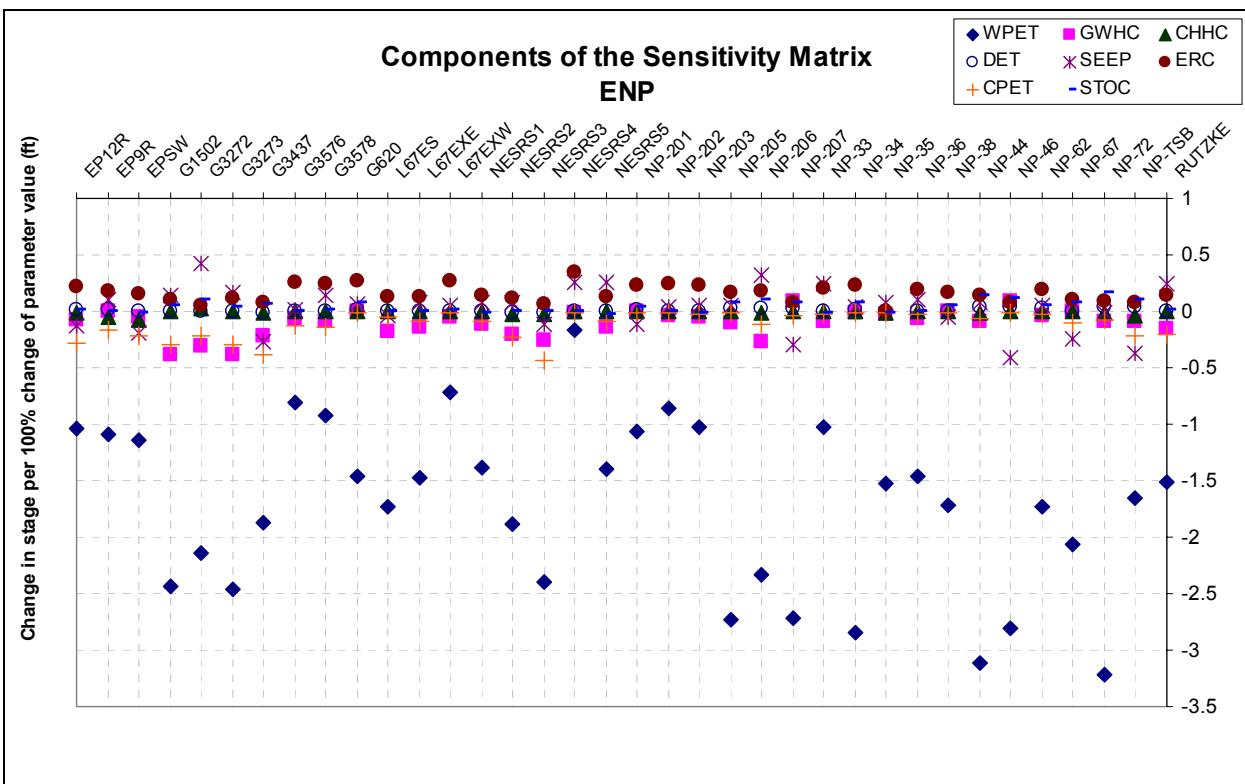


Figure 5.2.4 Components of the Sensitivity Matrix for ENP

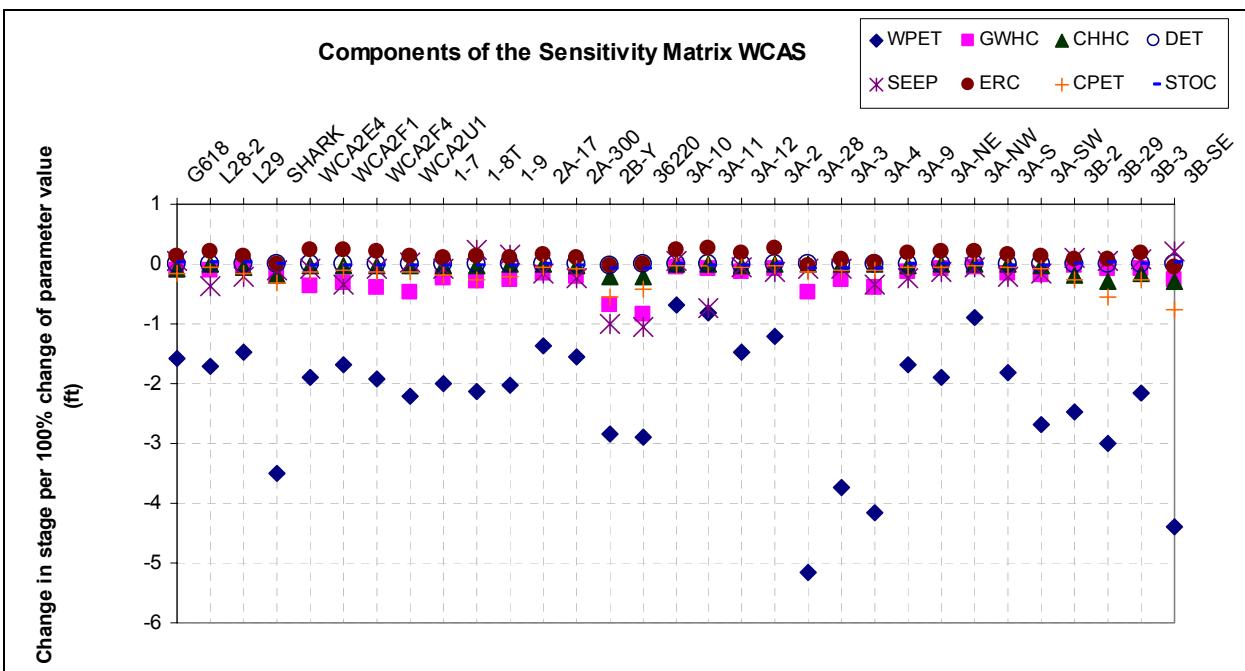


Figure 5.2.5 Components of the Sensitivity Matrix for WCAs

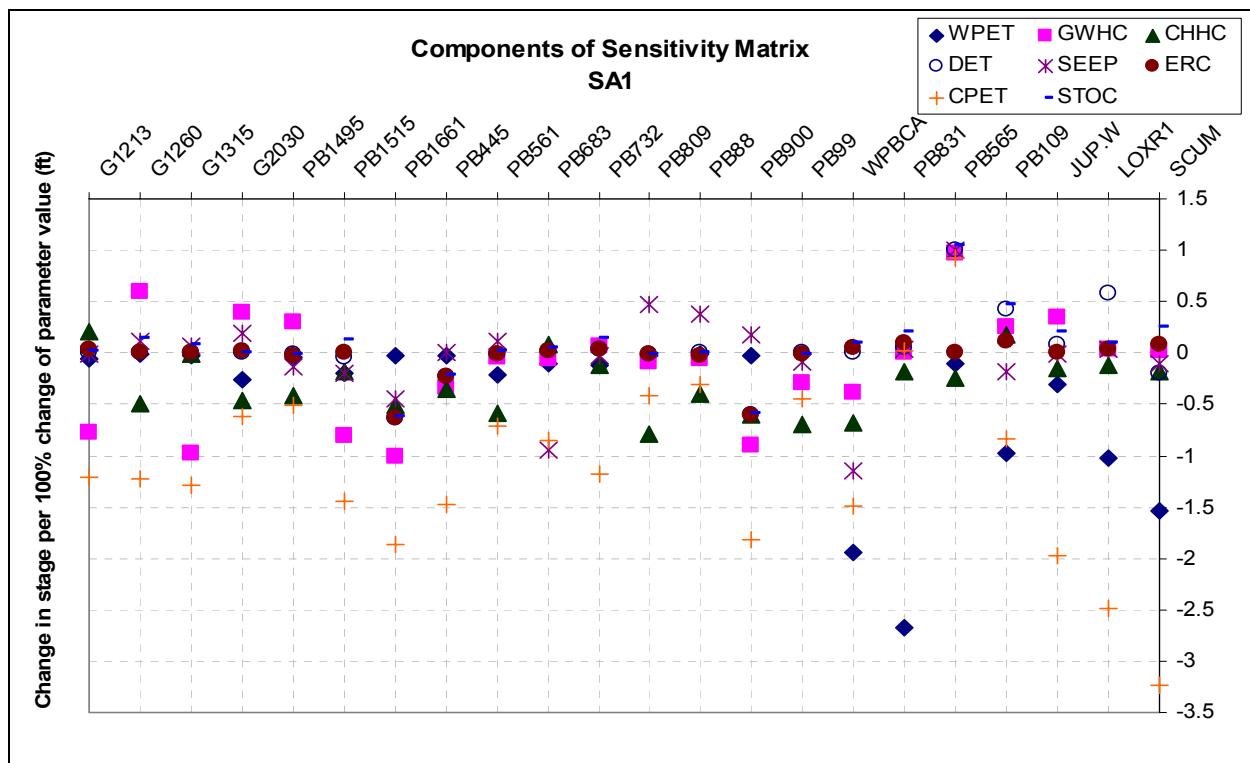


Figure 5.2.6 Components of the Sensitivity Matrix for LECSA1

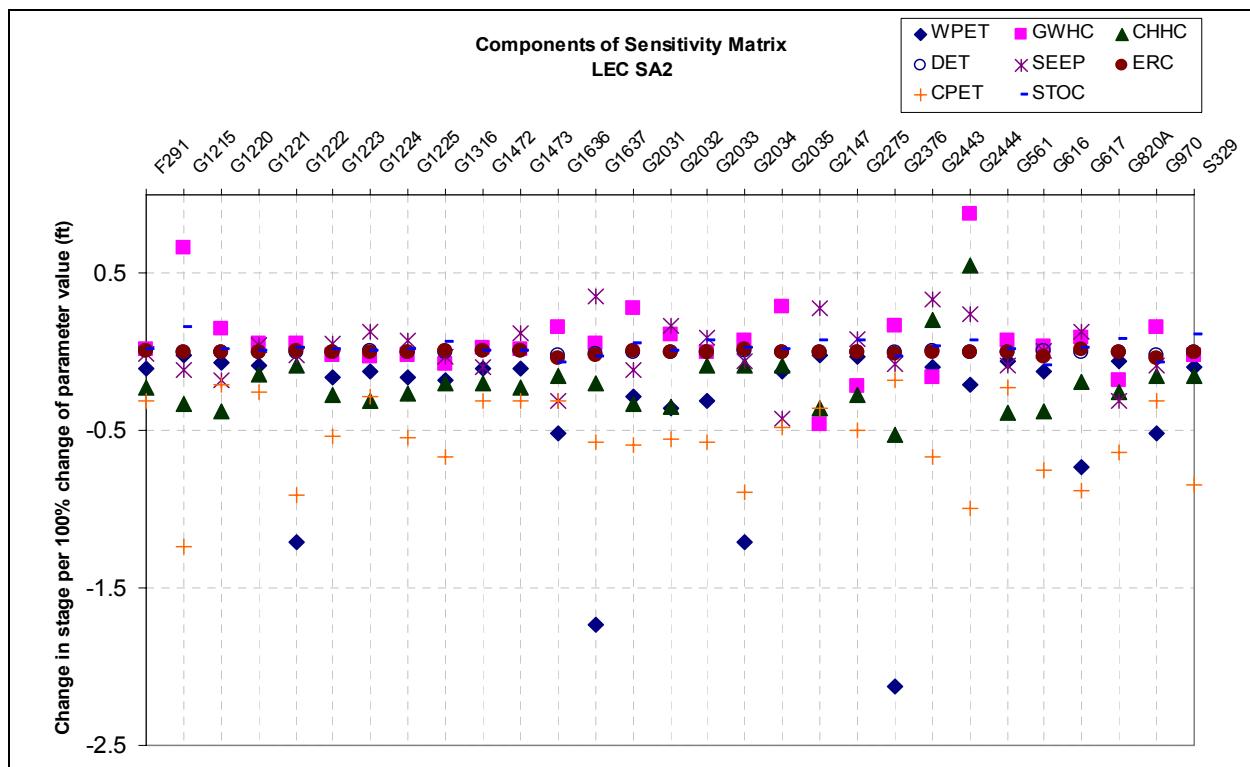


Figure 5.2.7 Components of the Sensitivity Matrix for LECSA2

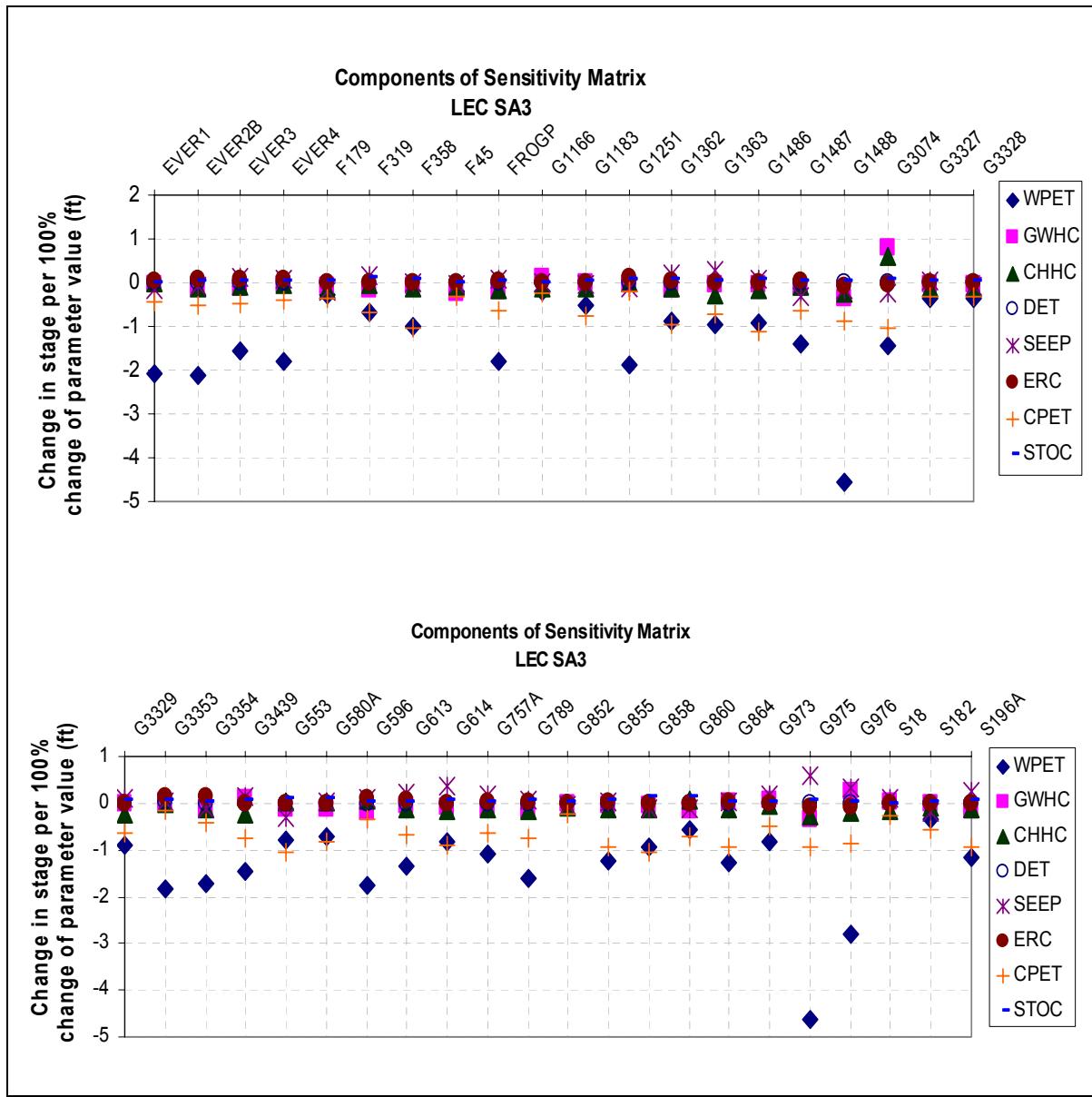


Figure 5.2.8 Components of the Sensitivity Matrix for LECSA3

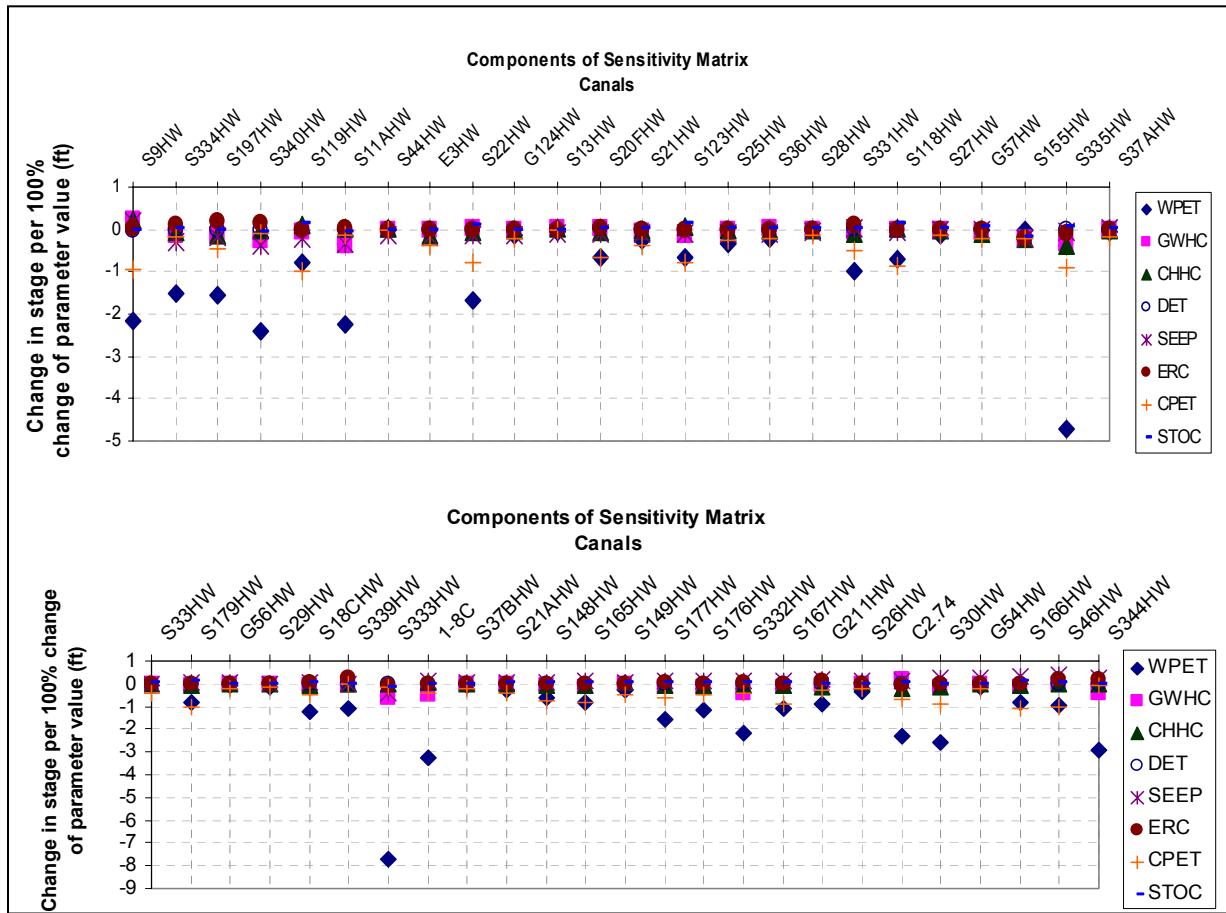


Figure 5.2.9 Components of the Sensitivity Matrix for Canals

The following observations can be made regarding Figures 5.2.3 – 5.2.9:

1. All regions are most sensitive to Wetland PET (WPET), especially BCNP, ENP, WCAs.
2. Coastal PET (CPET) has strong influence upon LEC areas.
3. Canal Groundwater Hydraulic Conductivity (CHHC) has strong influence on LECSA1 and LECSA2. The other regions, ENP, WCAs, LECSA3 and Canals are not sensitive to CHHC.
4. Effective Roughness Coefficient (ERC) has relative stronger influence in ENP. Canals and LECSAs only have slight impact from the variation of ERC value.
5. All regions are quite sensitive to the variation of Levee Seepage (SEEP).
6. Ground Water Hydraulic Conductivity (GWHC) variation affects the ENP, WCAs, LECSA1 and LECSA2 the most. All the other regions are just slightly influenced.
7. Detention Parameter (DET) has very slight influence upon all regions.
8. Storage Coefficient (STOC) has impact on BCNP, LECSA1 and LECSA2. All the other areas are affected very slightly.

A product of the SVD method is the parameter resolution matrix, as shown in Table 5.2.2, which is a measure of the independence of parameters used in a model. For the SFWMM, the resolution matrix is well resolved, all the elements are in the order of 10^{-8} , which means that each parameter is uniquely determined and should be treated separately as far as its influence in determining model output sensitivity.

Table 5.2.2 Parameter Resolution Matrix

	WPET	GWHC	CHHC	DET	SEEP	ERC	CPET	STOC
WPET	1.00	10^{-8}	10^{-8}	10^{-10}	10^{-8}	10^{-8}	10^{-8}	10^{-8}
GWHC	10^{-8}	1.00	10^{-8}	10^{-7}	10^{-9}	10^{-8}	10^{-8}	10^{-8}
CHHC	10^{-8}	10^{-8}	1.00	10^{-7}	10^{-7}	10^{-8}	10^{-8}	10^{-9}
DET	10^{-10}	10^{-7}	10^{-7}	1.00	10^{-7}	10^{-8}	10^{-7}	10^{-9}
SEEP	10^{-8}	10^{-9}	10^{-7}	10^{-7}	1.00	10^{-7}	10^{-8}	10^{-7}
ERC	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-7}	1.00	10^{-8}	10^{-8}
CPET	10^{-8}	10^{-8}	10^{-8}	10^{-7}	10^{-8}	10^{-8}	1.00	10^{-8}
STOC	10^{-8}	10^{-8}	10^{-9}	10^{-9}	10^{-7}	10^{-8}	10^{-8}	1.00

Additional useful information that can be derived from SVD method is the correlation matrix, as shown in Table 5.2.3. This matrix shows that there is only modest correlation between model input parameters. The range of values does not indicate positive or negative correlation. They range from 0.0 for no correlation and 1.0 for perfect correlation. Wetland PET and Effective Roughness coefficient show a relatively stronger correlation (0.22).

Table 5.2.3 Parameter Correlation Matrix

	WPET	GWHC	CHHC	DET	SEEP	ERC	CPET	STOC
WPET	1.00	0.10	0.03	0.00	0.02	0.22	0.10	0.00
GWHC	0.10	1.00	0.00	0.00	0.10	0.00	0.00	0.01
CHHC	0.03	0.00	1.00	0.01	0.01	0.01	0.00	0.01
DET	0.00	0.00	0.01	1.00	0.00	0.00	0.01	0.00
SEEP	0.02	0.10	0.01	0.00	1.00	0.00	0.00	0.00
ERC	0.22	0.00	0.01	0.00	0.00	1.00	0.02	0.02
CPET	0.10	0.00	0.00	0.01	0.00	0.02	1.00	0.05
STOC	0.00	0.01	0.01	0.00	0.00	0.02	0.05	1.00